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Study of the Effect of Recent Chemical Admixtures on the Modified Polysterene Concrete Properties

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Abstract

This article describes scientific studies carried out for production of polysterene concrete as modified with recent chemical admixtures. The purpose of work was to obtain physical-and-mechanical characteristics of the material that were necessary for use in the large-scale production of reinforced concrete wall panels, spandrels, flat slabs, short span slabs, etc. The performance test analyses offered rational ingredient compositions of a polysterene concrete mix and enabled obtaining the new information on its technological properties. Dependencies of the concrete strength, deformation and heat-insulation characteristics on percentage of chemical admixtures in the mix were determined. The scientific research are carried out by the employees of the FGAOU VPO 'Ural Federal University named after the 1st President of Russia B.N. Yeltsin''

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Keywords: polystirolbeton; fastness on compression; chemical additives; concrete; composite system; cement.

1. Introduce

Last years, in both Russia and abroad, a considerable increase in use of chemical admixtures for concrete production has led to growth in scientific studies of their influence on thermal and physical characteristics of various types of concrete.

On 12-16 May 2014, XII All-Russian (International) Conference on 'Concrete and Reinforced Concrete – Look into the Future' took place in Russian Academy of Sciences, Moscow. Russian and foreign scientists' presentation

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of new research works on use of chemical admixtures to improve concrete quality was one of the most significant events in the Conference Agenda.

Upon results of the Conference and within the framework of earlier started works, Construction Institute's Urban Development Department of Federal State Autonomous Educational Institution of Higher Professional Education «Ural Federal University named after the first President of Russia B.N.Yeltsin» (UrFU) decided to carry out comparative tests of effect of up-to-date chemical admixtures Relamix T-2 (Polyplast Company), KF-adhesive and air-entraining agent SDO-L on technological, physical and mechanical characteristics of the structural polysterene concrete in its Research Laboratory. The scientific research within the framework of V.A. Belyakov's thesis work [1] carried out jointly with Research Institute UralNIIAS was awarded Diploma at All-Russian Scientific Conference 'Science. Technologies. Innovations' in 2003, and was nominated for the Sverdlovsk Region Governor's award in 2004 [1].

The earlier research shows that polysterene concrete - being an efficient heat-insulation material [2] – can be used as a structural material, although polysterene concrete as a structural material has not been studied thoroughly enough. Anyway, use of high-strength polysterene concrete as the most efficient material from the point of view of cost effectiveness and energy-saving principles is in high demand currently and has good prospects in the longer term.

2. Research methods

The following two directions were determined in order to optimize structural polysterene concrete composition:

- improve concrete mixture parameters (workability, homogeneity, reduction in water or cement consumption) and, as a consequence, increase in strength of mortar matrix (intensification of aggregate cementing properties, cement hydration and setting processes);
- improve adhesion of polysterene concrete particles and mortar matrix (at the edge of their phase contact)

A task was set to prepare a substantially light (density range from 900 to 1,300 kg/m^3) and strong (from 7.0 to 16.0 MPa) polysterene concrete with good heat-insulation properties using up-to-date chemical admixtures. As a result of preliminary research, the best aggregate (in the Urals Region) for structural polysterene concrete was identified, namely, 0.64-1.25 fraction granulated blast-furnace slag from Serovsky Steel Works.

It should be noted, that the structural material under study is in demand for use in a large-scale production of reinforced concrete wall panels, spandrels, flat slabs and roofing, that is why, in the process of its development it was necessary to keep a low cost level of new concrete.

The polysterene concrete compositions were selected taking into account State Standard GOST 27006-86, based on methodology NIIZh6, where a required quantity of each ingredient was determined by calculation and experiment method. Portland cement CEM I 42.5N (without mineral admixtures) from Neviansky cement producer was used for tests. Specimen tests were carried out by methods stipulated by GOST 10180-2012 [3]. Quantities of water were selected depending on the required concrete workability.

Currently, most of research works studying effect of chemical admixtures on concrete properties are valued mainly from the point of view of their rheology [4]. In 2000, VI Conference (in Nice) on super-plasticizers and other chemical admixtures highlighted compatibility of an admixture with composition and properties of other elements of the composite system (aggregates and cement) as a top priority problem. Earlier, in 1960-1970, O.P. Mchedlov-Petrosian [5] made an important contribution to research of chemical admixture effect. In our opinion, this problem is more pressing for structural polysterene concrete, rather than for heavy-weight concrete and some types of light-weight concrete.

Hydrophobic properties of light-weight polysterene aggregates with closed pores (charge on the polysterene granule surface takes part in the process of wetting) can exert unfavorable effect, as strength of phase contacts (hydrated cement-to-particle surface binding) decreases. Owing to that, it becomes necessary to use a chemical admixture for changing this charge into positive in order to make the granule surface show hydrophobic properties. Alongside with that, it is expedient to use admixtures increasing mortar workability (C-3, TEA, SDO) simultaneously with admixtures improving durability of the set cement at the edge of contact with polysterene concrete granules (lime milk and epoxy resin), as well as binding activity of slag aggregate grains (solution of NaOH).

Thus, at initial stage of the tests the following different chemical admixtures were tested: super-plasticizer C-3, TEA, sodium hydroxide, PVA, epoxy resin jointly with polyethylene imine, as well as lime milk and air-entraining admixture SDO.

Adding plasticizer C-3 in the amount of 0.5% and 0.8% of cement mass to polysterene concrete enabled to get 2.1 MPa and 2.5 MPa increase in compression and bending strength of the specimens, respectively, as compared to reference ones. Water-need for binding agent mixing decreased by 40% and 55% of water-need for reference composition due to increase in mix workability. Freeze-and-thaw resistance of the cubes was at least 100 cycles.

Adding 0.1% and 0.5% of TEA ensures fast rates of polysterene concrete mix setting accompanied by high heat emission at the time of initial setting. Nevertheless, the final setting time comes approximately in 24 h and later (with increase in admixture concentration). According to V. Ramachandran [6], the above effect is explained by the fact that there occur acceleration of reaction between C_3A and gypsum in the system and fast formation of ettringite (chalcomorphite) phase in cement mortar.

The authors herewith confirm a plasticizing effect of the admixture. The effect was expected upon results of previous tests of admixture TEA effect on conventional concrete that allowed keeping the required fluidity of polysterene concrete mix at 45% decrease in water consumption as compared to the reference one. Use of admixture C-3 together with TEA in mortars compensates to some extent for a slow-down of the final setting time, but no significant increase in specimen's strength has been observed. Presence of slag aggregate grains in structural polysterene concrete weakens the effect of this chemical admixture on properties of the material under study. A negative factor is also a higher cost of chemical admixture, i.e. RUR75 per liter.

While mixing the polysterene concrete with NaOH solution we observed a high exothermic effect and a considerably higher speed of loss in workability. A destructive effect of alkaline agent NaOH on colloid film of silicic acid on the surface of slag aggregate grains largely facilitated water diffusion into the grains and accelerated hydration and polysterene concrete setting processes. Thus, one of the ideas of physical-chemical mechanics – Rebinder's paradox, i.e. strengthening a structure through destruction of its components – was indirectly confirmed. Use of chemical admixture NaOH in form of 3% to 5% concentrated solution led to 15% increase in specimen material strength as compared to the reference one. This is supposedly due to formation of linear-type crystal concretions at cement matrix contact with aggregate grains. The concretions are a product of alkali reaction with activated alumina, silica, silicates and calcium sulfide that make part of blast-furnace slag. Physical-chemical analysis of the material structure, in our opinion, would enable to prove this supposition and would determine contents of crystal concretions within the matrix volume (probably 15-20%). Alongside with that, use of sodium hydroxide with chemical admixtures SDO or SDO-L enhances air entrainment owing to additional alkali saponification of acidic resins contained in the above admixtures.

80-% increase in specimen compression and bend strength achieved by use of epoxy resin added with acetone thinner and PEI hardener compensates for almost double increase in polysterene concrete cost owing to high admixture cost. Freeze-and-thaw resistance of cubes was not less than 50 cycles. Various admixture combinations were tested to select the best raw ingredient compositions in order to ensure necessary polysterene concrete physical-mechanical and heat-insulation properties.

Optimal admixture combination for production of structural polysterene concrete included use of plasticizer C-3 with SDO and preliminary treatment of polysterene granules with lime milk. Comprehensive consideration was given to market prices of both admixtures and proposed concrete, to simplicity of their use and to overall material property improvement effect.

The best results were achieved after adding 0.5% of C-3 and 0.25% of SDO as to cement mass followed by treatment of specimens in steam chamber during 24 hours at temperature of +800C. Preliminary coating of polysterene concrete granules with lime milk enabled to get extra 20-25% increase in strength of polysterene concrete specimens. At the same time, insignificant reduction of plasticizing effect from use of C-3 and SDO was observed. Apart from that, the nature of destruction of polysterene specimens at compression changed. It is likely, this was due to increase in phase contact strength between polysterene concrete granules and cement brick.

While mixing a concrete mix without air-entrainment admixture, but with C-3 admixture, a part of the air gets lost owing to low viscosity and dispersed condition of polysterene concrete. Many authors dispute positive effect of C-3 and its analogues on freeze-and-thaw resistance of concrete declared by their manufacturers. In our opinion, positive effect is insignificant even in the best case (applicable for light-weight concrete). This led to a decision to study physical characteristics of polysterene concrete specimens with use of C-3 added with SDO and without it, as intended for enhancement of polysterene concrete freeze-and-thaw resistance by way of air entrainment. However, it is known that durability is an inverse function of a material porosity. That is why, it seems more expedient to use an alternative admixture featuring compatibility with C-3 and improving concrete heat-insulation characteristics. According to earlier studies, use of air-entrainment admixture SDO for producing polysterene concrete with medium density of γ= 700-800 kg/m^3 reduces its compression strength by 10-10.5% as compared to reference.

Later, emergence of new chemical concrete admixtures in the market offering better properties (from the point of view of their producers), led to a need to carry out comparison performance tests of strength of structural polysterene concrete specimens. It should be noted that new generation admixtures (like polycarboxylates and acrylic copolymers with a comprehensive mechanism of action) produced by foreign companies are not competitive in the Russian market due their high costs. High efficiency of such admixtures is supposedly owing to the fact that they create steric repulsive forces in adsorption films surrounding cement particles [7]. Action of steric effect is much stronger than that of electrostatic repulsive forces between particles that are linearly connected with cement-water paste flowability. It is a pity that these chemical admixtures are not universal and not compatible with every Russian cement composition. This means that effect of retention in time of admixture action is limited by cement properties and chemical composition [8,9]. For example, admixture forming part of Concern Degussa's EMACO mixt is highly efficient only with cement grade CEM I 52.5N produced by ZAO Oskolcement Ltd.

Lignosulphate group chemical admixtures available in form of industrial waste from paper production (lignopan B 1-4, KMX, etc.) are less efficient than C-3 and its derivatives (for example, admixtures of Relaxol group) and are inconvenient enough in use due to instability of their composition and properties. A positive factor is a relatively low cost of those admixtures.

Brief characteristics of new chemical and air-entraining admixtures selected for comparison performance test:

1. Chemical admixture Relamix T-2 was designed on the base of well-known superplasticizer C-3 used for heavy-weight concrete in construction industry for over 50 years. It represents mixtures of sodium salts of poly-methylene-naphthalene-sulfo-acids featuring different molecular mass added with system of strength gain acceleration. Lead specialists of Reinforced Concrete Research Institute NIIZhB (V.G. Batrakov, M.I. Brasser) approved the admixture. Polyplast-UralSib Company, Pervouralsk, Russia is the producer. At the time of this article, price of one kilogram of Relamix T-2 was RUR85 being from RUR12 to RUR2.5 higher than a kilogram of C-3.

2. Air-entraining admixture SDO-L is a modified version of well-known SDO, which is widely used for production of heat-insulation polysterene concrete nowadays. SDO-L is designed to reduce density and improve workability of concrete mix, as well as to improve heat-insulation properties of concrete. Its action is by principle of porosity formation of cement-water paste. CDO is produced owing to the best ratio of resin and fatty acids (in other words, saponifiable and unsaponifiable) in the process of treatment of certain leaf wood species, for example, birch tree. According to its developers, SDO-L is a product of wood pitch saponification, i.e. dry wood distillation (pyrolysis). An organic part is separated by way of extraction followed by distillation. Vneshkhimopt Company develops and offers it in the market. In the Urals Region, the supplier is Lakra Ltd.

3. Chemical admixture KF-adhesive was developed specifically for polysterene concrete. Its principle of action is based on mechanism of electrochemical adhesion reactions (like gold-plating, chrome-plating, but without power). Adhesion creates a field on the surface of granules that has a charge opposite to that of cement particles, which, in its turn, attracts cement to polysterene. This enables to achieve a balance of polysterene and cement-water paste masses, thus allowing its even mixing. The admixture was designed by specialists of Tribus Company, Volgograd.

3. The results of the work

The authors have determined that addition of chemical admixture Relamix T-2 in the amount of 0.6% of cement mass increases polysterene concrete mix workability from P1 to P5 as to GOST 10181-2014. Water reduction decreases water consumption by 30%, while polysterene concrete durability growth during 28 days achieves 3.7 MPa as compared to durability of reference specimens made without admixture. It is likely that this fact is due to interaction of admixture-composing chemical compounds (strength gain accelerating system) with activated alumina, silica, silicates and calcium sulphide forming part of blast-furnace slag. Use of Relamix admixture in the amount of 1% and more of cement mass leads to disintegration of polysterene concrete mix, to a certain drop in setting speed and to air entrainment effect.

Increase in cost of consumable materials for structural polysterene concrete having a density of approximately 1,000 kg/m^3 and added with 47.5 kg of Relamix per 1 m^3 will be about RUR100 (12 to 13% of polysterene concrete cost). However, in producers' opinion, efficiency growth (in other words, overall cost reduction, including wages, overhead and other expenses) will decrease 8 times.

Use of SDO-L in polysterene concrete brings to increase in its volume due to air entrainment. Hence, while adjusting its technological parameters it is necessary to decrease volume of polysterene concrete and increase that of cement, which lead to a certain fall in initially set heat-insulating characteristics. Heat transfer resistance factor was 0.14 W/m °C at specimen density being at the range of 870-900 kg/m^3. Freeze-and-thaw resistance of cubes was at least 100 cycles.

Effect of KF-adhesive is that concrete mix becomes compact, which, in its turn, improves to some extent (according to authors' tests), heat-insulating and durability characteristics of tested polysterene concrete specimens. Heat transfer resistance factor was also 0.14 W/m °C at specimen density within the range of 950-975 kg/m^3 (higher than density of specimens added with SDO-L). Heat-and-thaw resistance of cubes was not less than 100 cycles. Increase in cost of consumable materials for structural polysterene concrete with use of about 50 kg of admixture per 1m3 will be RUR110.

Use of air-entraining admixture SDO-L enjoys higher demand in heat-insulation polysterene concrete not requiring extra durability (in the range of densities from 150 to 600 kg/m^3). At the same time, chemical admixture KF-adhesive, as to its mechanism of action, has more prospects for use in structural polysterene concrete in the density range of 900 to 1,400 kg/m^3. Table 1 shows results of selection and test of raw polysterene concrete ingredient compositions obtained by the authors. They allow concluding that the best combination of chemical admixtures will be to use plasticizer Relamix T-2 together with KF-adhesive in lower concentrations and preliminary treatment of polysterene granules with lime milk.

Table 1. Effect of chemical admixtures on structural polysterene concrete parameters and durability for production of middle layer of triple-layer walling panels and window headers

Chemical admixture, %	Amount of cement, g	Granulated blast-furnace slag, g γ=2.41 g/cm^3	Polysterene, ml	Water, ml	Concrete mix		Specimen density, γ, g/cm^3 (conditions of natural moisture content)	Specimen moisture content W, % (m_{wet}-m_{dry})	Compression strength, MPa, mature, days	
					W/C	cone			7	28
Without admixtures	700	250	800	350	0.50	3.0	1,090	4.4	4.0	5.7
C-3, 0.5 of cement	700	225	800	220	0.31	2.5	1,024	3.0	5.4	7.8
C-3, 0.8 of cement	665	215	900	150	0.23	2.5	975	2.0	6.0	8.2
C-3, 0.5 + CDO, 0.25 + lime milk	795	255	835	242	0.30	3.0	1,270	4.7	9.8	15.8
C-3, 0.5 + TEA, 0.5	695	234	900	190	0.27	3.0	1,030	3.9	4.2	6.4
Relamix T-2, 0.6 of cement	650	215	900	260	0.4	3.0	1,030	3.0	7.4	9.4
SDO-L, 0.25 of cement	570	180	765	240	0.42	3.0	870	6.0	4.44	5.7
KF-adhesive, 0.25 of cement	623	210	900	233	0.37	3.0	975	2.6	4.2	6.0

Note: Polysterene concrete compositions are represented as per 1 litre of mix.

4. Conclusion

It should be noted that according to results of the previous tests the rate of strength gain of polysterene concrete made with granulated blast-furnace slag aggregate lasts much longer (60 days as compared to 28) [10-14]. It is supposed that difference in strength characteristics of polysterene concrete with use of the above admixtures will reduce to some extent in the course of time [15-20].

The tests to develop polysterene concrete compositions and to test its thermo-physical properties resulted in obtaining a new material for building structures with good durability and heat-insulation characteristics to be intended for production of reinforced concrete wall panels, lintels, floor slabs and short span slabs.

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